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5 October 1990

Dr. Randall Jacobson 696 4121
Office of Naval Research
Code 1125 GG
800 N. Quincy St.
Arlington, VA 22217-5000

Dear Randy:

I am enclosing a brief report of the research completed under Grant N00014-89-J-1017, *Very low frequency seismo-acoustic scattering from a rough seafloor*. We made considerable progress in developing techniques for computing the scattering from a rough surface. To date, the most useful of these has been the Kirchhoff-Helmholtz technique largely because of its intrinsic efficiency. We have had great success with this algorithm in modeling scattering at small angles of incidence or large grazing angles. The method works quite well at shallow angles, but the accuracy is questionable. Several papers are in preparation at IGPP right now using this technique and the acknowledgements will reference this important grant. The finite difference algorithm is also operating very smoothly and is being used to test the accuracy of the Kirchhoff-Helmholtz method.

As you're aware, the issue of shallow angle backscatter has become of substantial importance in the Navy. The Acoustic Reverberation Special Research Program (ARSRP) builds on much of this work and my colleagues and I are continuing with our modeling efforts which were initiated under this grant. I hope that you will find the report interesting and that we can continue to discuss this from time to time. Please let me know if you have any questions.

Sincerely,

John A. Orcutt
Director

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TITLE: Very Low Frequency Seismo-Acoustic Scattering From a Rough Seafloor

INVESTIGATOR: John A. Orcutt
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OBJECTIVE: The long range scientific objective of this research is to understand and exploit the interaction between seismic or acoustic waves and the underlying oceanic crust and sediments. We are studying this problem using body and interface waves, as well as seismic and acoustic "noise," while rigorously considering the effects of anelasticity and vertical and lateral variations in both compressional and shear velocities in the earth.

BACKGROUND: In order to model completely the response of an irregular seafloor and heterogeneous subbottom to incident acoustic energy, numerical methods are required. Our work so far has concentrated on the boundary integral (BI) method and the asymptotically related Kirchhoff-Helmholtz technique. We have also implemented finite difference methods, which although less efficient that BI methods, can address models of arbitrary complexity including elastic heterogeneity and/or attenuation in the subbottom.

APPROACH: We have studied ways to improve the speed and accuracy of the different methods, so that they will be practical for three-dimensional problems. In addition, we are comparing theoretical results with seafloor scattering data collected during seismic reflection experiments on the East Pacific Rise.

RESULTS:

1. *Boundary Integral Method*

We have improved the efficiency of the BI method by implementing an iterative Chebyshev method of matrix inversion (Olson, 1987), and are currently working on a Jacobi method which will provide even greater efficiency in the case where the scattering matrix is diagonally dominant (i.e. the interface has only small deviations from planar).

2. *Finite Difference Method*

Our finite difference algorithm uses a staggered grid (in which stress and strain are computed at different model points), eight-point convolutional operators to evaluate derivatives, and absorbing boundary conditions to eliminate edge reflections. We have implemented this method on our HP/Apollo DN 1000\ superminicomputer in our laboratory. Figure 1 shows results of a simple 2-D example in which waves generated from a point source in the ocean are reflected and scattered by an irregular seafloor.

3. *Kirchhoff-Helmholtz*

Although BI and/or finite difference methods are required for accurate modeling of scattering at the seafloor, they are inefficient for studying wave propagation within the ocean, where much simpler and more efficient methods such as Kirchhoff-Helmholz can be used. We have implemented such techniques to model both three-dimensional bottom reflections and elastic waves refracted through the subbottom, using accurate maps of seafloor topography available from SEABEAM profiling. Figure 2 shows isochrons (lines of equal travel time) for a refraction experiment near the East Pacific Rise and the computed response function for a surface explosion as recorded by an ocean bottom receiver.

4. *Hybrid Methods*

We have begun development of hybrid schemes which include finite differences where required at localized complex regions in the model (such as the sea floor), but which use more efficient methods for the remainder of the model. The hybrid finite difference scheme is illustrated in Figure 3. Acoustic energy is propagated within the water column using very fast ray theoretical methods. The interaction with the seafloor is calculated using a three-dimensional finite difference grid which includes the seafloor interface and thin layers of the overlying water and underlying sediment and/or basement. The vertical dimensions of this grid can be kept relatively small, thus minimizing computational requirements and allowing the solution of three-dimensional problems.

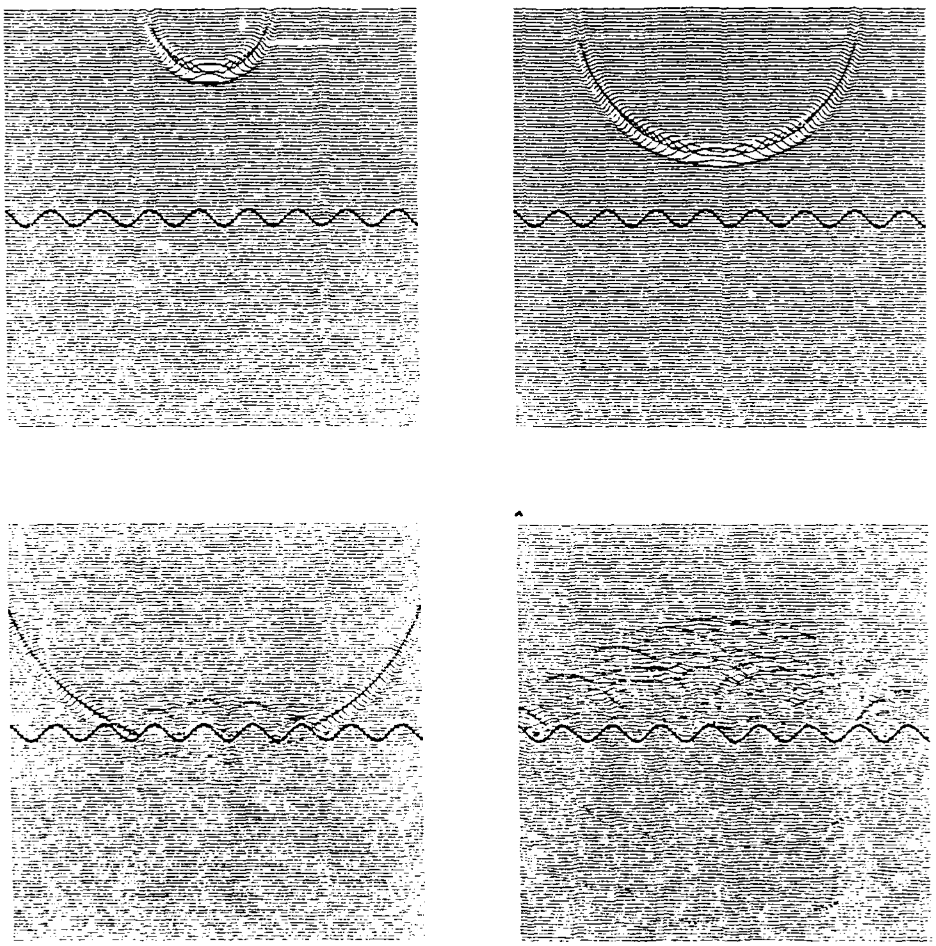

Figure 1. Finite difference results for incident and scattered energy for a simple model with an irregular interface between an ocean and elastic basement. The vertical component of acceleration is shown for a point source at the top of the model. The squares are 25 km on a side; results are shown at 1 second increments. This example illustrates the complicated scattering behavior which can result when the acoustic wavelengths are comparable to the wavelength of the interface topography.

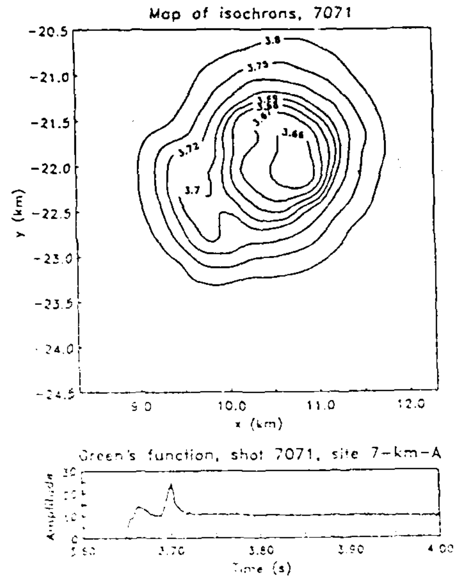

Figure 2. Travel time isochrons for an irregular seafloor used in the implementation of a Kirchhoff-Helmholtz based technique for computing acoustic waves refracted through an elastic subbottom. The lower plot shows the response function for a source at the sea surface as recorded by a seafloor receiver.

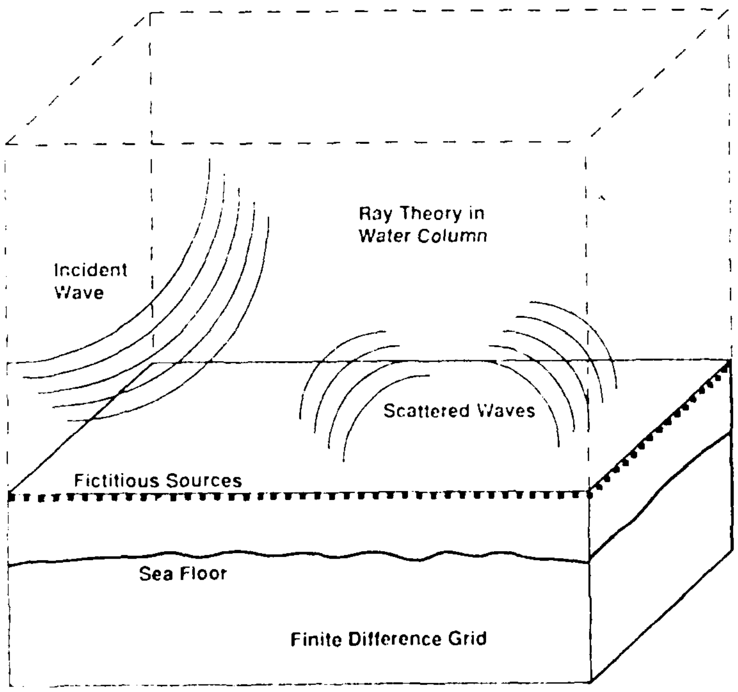

Figure 3. A schematic diagram of the hybrid Finite Differences and Kirchhoff-Helmholtz formulation. A FD algorithm is used to solve the vector wave equation near the heterogeneous seafloor. The solution, sensed on a plane within the water column, is propagated to the sea surface using a simple technique such as Kirchhoff-Helmholtz.